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Issues Relative to the Control of Large High Speed Unmanned Vehicles for Use in Crash Rescue Operations

A Technical Paper Presented to the American Nuclear Society, Ninth International Topical Meeting on Robotics and Remote Systems, Seattle, WA, March 4-8, 2001

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ISSUES RELATIVE TO THE CONTROL OF LARGE HIGH SPEED UNMANNED VEHICLES FOR USE IN CRASH RESCUE OPERATIONS

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ABSTRACT

This investigation was performed to provide a migration path for the standard vehicle control unit used by the Air Force Ground Robotics Group at AFRL/MLQF in anticipation of requirements to control large high speed vehicles for crash rescue and fire fighting applications on military runways. The control systems of small, slow moving machines common in research and development platforms have historically ignored vehicle dynamics beyond basic parameters such as acceleration, steering and braking. The limited velocities of these vehicles does not significantly impact or limit the turn radius and turn rate to introduce conditions dangerous to the vehicle. In contrast, a large and/or fast vehicle may rollover during a sharp turn even at moderate speeds.

The success of this effort is reflected in the minimal development time experienced through exploiting the existing control system and addressing the known differences in control parameters. Although the goal of the effort was only to obtain characterization data for the vehicle control software prior to actual implementation, the prototype control system provided operation at low speeds allowing the developers to test algorithms outside of a simulation environment. Higher speed operation is available within the current implementation, but safety constraints have not been fully implemented.

Completion of the first phase of this project indicates a high probability for success in both the second and third phases. Already, the braking system has been implemented, investigations of the use of digital video to reduce radio frequency transmitters and receivers have been conducted, turrent control via the joystick implemented and tested, and remote control of all functions have been verified. The integration of system parameters measured during phase I, and the design and implementation of safety mechanisms will provide for the base platform for the Remote Crash Rescue Vehicle.

1.0 INTRODUCTION

AFRL/MLQF at Tyndall AFB has been actively investigating and demonstrating the application of remote controlled and semi-autonomous vehicle technologies for hazardous mission and material handling for over 10 years. Leveraging the investments already made in past efforts provides a foundation for and reduces risks associated with current efforts. The use of Unmanned Ground Vehicles (UGVs) by government as well as civilian agencies has demonstrated phenomenal growth over the last ten years. The need for robotic applications has predominately been driven by the desire to remove personnel from hazardous environments whenever possible. Recent work with advanced semi-autonomous Unexploded Ordnance (UXO) detection systems has demonstrated the potential of robotics in remote sensing applications such as mine detection and mitigation as well as within the environmental community in terms of hazardous material detection systems. Within the robotics community core elements such as common system/sub-system interface architecture, systems messaging architecture, communication protocols, remote sensing systems, and operator control systems can be standardized in order to fully exploit the robustness of present and future robotic systems while minimizing the amount of re-engineering generally required. Standardization provides the avenue to develop robust, expandable and multi-purpose systems. The control architecture of the Crash Rescue Vehicle system was migrated from a slow moving tracked vehicle. This research provides a foundation not only for describing the contrast in these control systems, but to emphasize the utility of a set of core components in the standardization of unmanned systems.

The selection of a platform for a crash rescue/decontamination vehicle was based on availability within AFRL's assets and an independent assessment through previous work conducted by Cybernet Systems Corporation.[1] In their analysis, they determined a priority of systems that could address a firefighting mission from a remote control scenario while attacking different types of fires. The P-19 fire truck was selected in part from its ranking in the Cybernet work and AFRL/MLQF has access to 2 systems in-house available for research and development.

Other research and development dates back to 1985 when AMTEK/Offshore Research and Engineering Division performed a conceptual design study for the Air Force on a Remotely Operated Robotic Firefighter.[2] During this effort an Air Force P-4 Firetruck was fitted with the remote control system and demonstrated. After a successful demonstration, the remote system was disassembled. The recommendations and conclusions of this effort emphasized further work in Human Factors engineering—an area of research prevalent today in remote controlled systems development.

The research and development effort as reported herein was designated the P-19 Remote Crash Rescue Vehicle, Phase I, Concept Evaluation. The Concept Evaluation of the Remote Crash Rescue Vehicle (RCRV) addressed the following objectives:

- Evaluate the "proof of concept" by controlling the vehicle from within the P-19 through the use of joystick controls feeding a Vehicle Control Unit (VCU). The VCU will control the throttle and steering. Joystick inputs to the VCU will be translated to actuator commands and/or VCU outputs;

- Characterize vehicle performance parameters including turn radius at varied speeds, braking distance, and other critical thresholds as identified during the effort;
- Determine the influence of operator reaction time and system latency on total system performance, response time, and safety requirements.

The remainder of this document summarizes this effort and reports the conclusions and recommendations identified by the developers and engineers.

2.0 PROGRAM DESCRIPTION

The purpose of this effort was to access the implementation of the vehicle control unit used on the All Purpose Remote Transport System (ARTS) for control of a large firefighting system.[3] The effort was divided into 3 phases with the end of each phase addressing varied control issues. Phase I, Concept Evaluation, addresses the basic driving functions of the vehicle. The "Proof of Concept", characterization of vehicle performance parameters, and evaluation of the operator's control of the vehicle are the three primary tasks for this phase. Results from Phase I will be analyzed and incorporated into the specification and design of Phase II, Remote Vehicle Operations. During Phase II the completion of the implementation of the remote vehicle control system will be performed by introducing braking and shifting into the control system Additionally, Phase II will result in an operational vehicle control system that allows an operator to drive via a radio frequency (RF) link. Phase III, Fire Fighting, will further the operator's capabilities from a remote station by introducing controls for turrets and agent selection. To date, only the first Phase of the project is completed. Portions of the Phase II and III have been started and are described in the Final Report[4].

Phase I used a modified basic vehicle control unit (VCU) previously developed for the ARTS. A tethered joystick for an operator to control throttle and steering was provided to allow control and testing from within the vehicle. Re-use of the design architecture of the ARTS was implemented to the maximum extent possible. However, many vehicle dynamics issues merit significant changes in the ARTS software architecture. By using the ARTS VCU and the existing Controller Area Network (CAN) bus architecture, the development time was reduced drastically while allowing for further characterization of the transportability of the P-19 VCU to other platforms types.

The early assesment of human factors presented the unique circumstance in which one operator could not perform the crash rescue mission alone. The P-19 is designed for three operators inside the cab. The rationale for this becomes apparent when designing the remote control interface. Typical operation during a fire on an airfield requires moving the vehicle and targeting the fire with the turrets. Although not implemented beyond basic driving, the operator control requirements are identified and certainly introduce complexity.

3.0 SYSTEM DEVELOPMENT

The P-19 has a variety of points modified to install control system components necessary for phase I analysis. For throttle control, an actuator is installed in the engine compartment where a pneumatic valve manipulates the fuel flow into the engine. This actuator is back-

drivable, therefore avoiding any physical engagement/disengagement issues associated with non-back-drivable devices. For steering control, a motor is attached below the steering wheel that engages the steering column for manipulation.

STEERING

This steering module was broken down into 3 major components: Steering motor, Devicenet node assembly, and steering angle encoder. In order to initialize the steering system and avoid performing a homing sequence (determining the limit of travel of the wheels) at each instance of system start-up, an absolute encoder was used to provide a constant angular indication of the wheels. Control of the steering is dependent upon several factors such as wheel angle, speed, and the rate of turning.

The point of actuation for control of steering was the drive-angle unit (a 90° angular change) mounted just below the steering wheel assembly. At this point, the drive-angle unit was modified to extend the shaft through the backside of the drive-angle unit housing. This unit required minimal modification due to a back-plate already installed to support the back-end of the shaft. This back-plate was identical to the front-plate which the shaft already extended through to connect to the steering wheel with the exception of the hole for the shaft. Another front-plate was purchased and installed, replacing the back-plate, and a new shaft was fabricated to extend through the other side for remote actuation. A belt-type pulley attached the drive-angle unit to a steering motor; otherwise, no modification to the drive-angle unit housing was necessary.

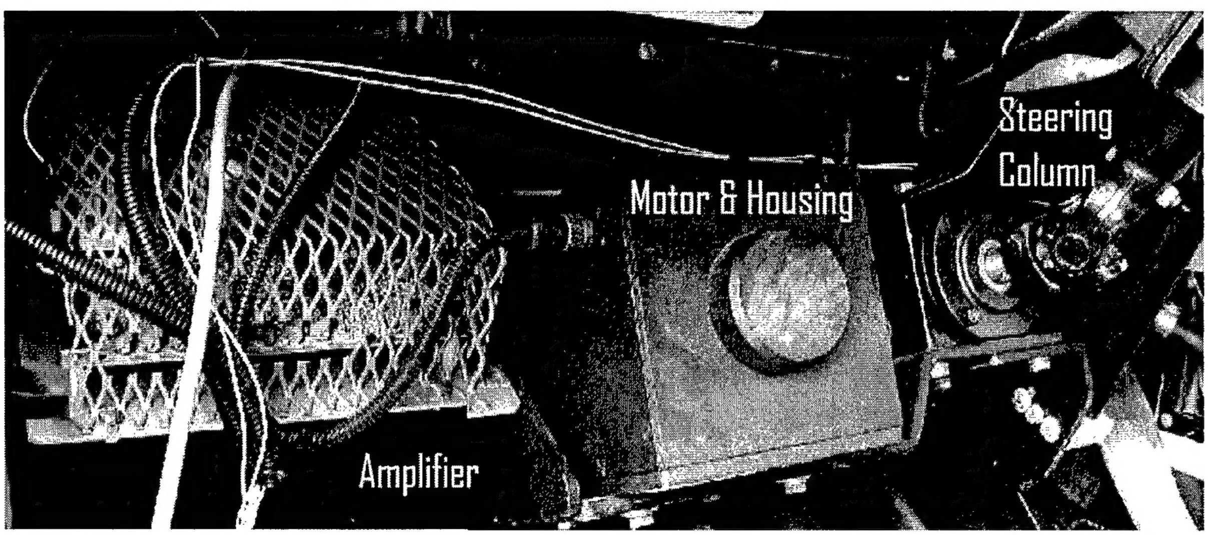


Figure 1, Steering Drive Motor Assembly

For this application, a DeviceNet-ready absolute encoder was selected to provide constant angular position information in which to provide for continuous, absolute position of the front wheels. Upon startup, if the wheels are not aligned with the neutral position of the joystick, the steering motor will command the wheels to turn to a neutral position based on information from the encoder.

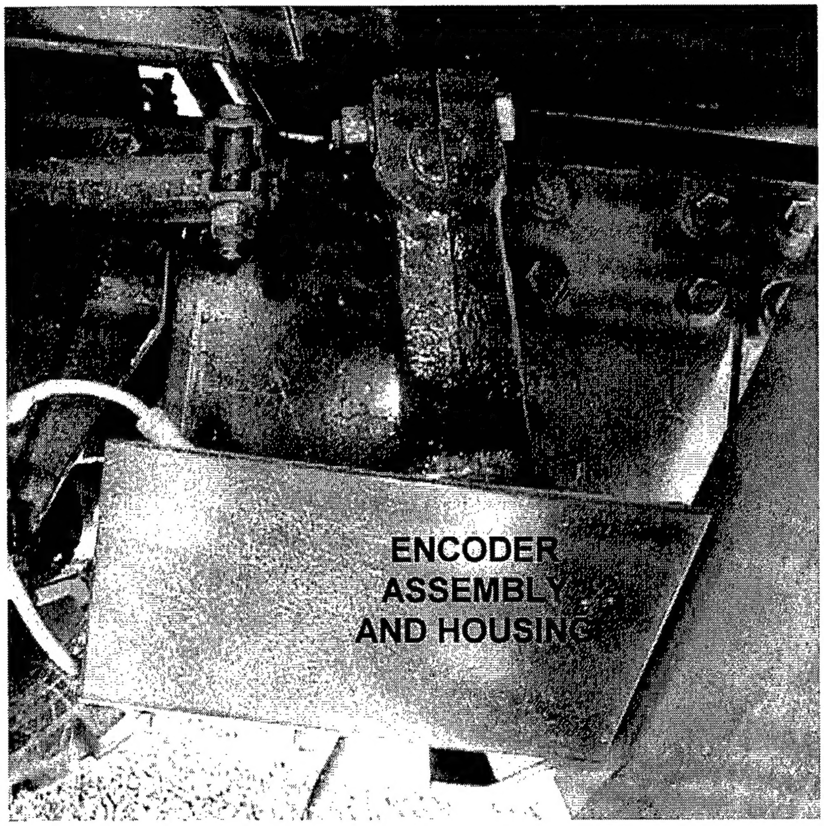
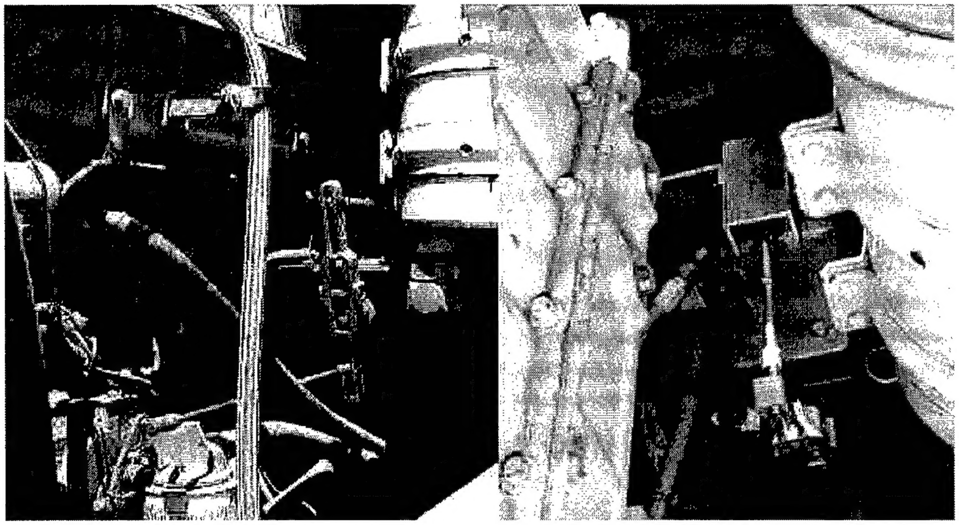


Figure 2, Pittman Arm Steering Encoder

THROTTLE

A pneumatic throttle valve located in the engine compartment operates a throw lever that controls fuel flow to the carburetor. As an operator presses on the accelerator, the pneumatic valve is opened or closed and the lever responds respectively. It is important to note that throttle control is either on or off (accelerating/decelerating) under manual operation and requires constant manipulation to maintain an intermediate speed other than full open. The lever on the pneumatic throttle valve was mirrored to allow for attaching an electrically operated actuator. The actuator communicates with its controller that is connected to a DeviceNet Node for remote operation. An ADDCO actuator was chosen due to its reliability proven on the ARTS and the fact the ADDCO actuator can be back-driven while power is not applied to allow for manual operation of the vehicle. No actuator or motor will have power during manual operation, only when the operator engages the "remote engage" switch located in the vehicle cab will these devices have the power to move.



Rear View **Top View**

Figure 3, Throttle Assembly

SOFTWARE

In this project, a goal was to expedite software development time by using the existing ARTS software source code where applicable. Some of the vehicle independent ARTS software such as DeviceNet-to-computer interface code could be utilized. However, the great deal of the software was extremely specific to the ARTS vehicle and a different software approach had to be generated. The differences between the P-19 control mechanisms, Ackerman style steering and automatic transmission, and the ARTS control mechanisms, linear Hydrostatic Transmission on a tracked vehicle, required software changes at the architectural level. The approaches to these changes were to maximize software portability and reuse by designing the software to be robust enough that it could be easily modified for most vehicle control application.

The P-19 has many different operating characteristics (wheel vs. track, speed etc.) that obviously distinguish it from the ARTS platform. To create an accurate model of the vehicle, variables such as velocity, heading, pitch, roll, understeer and oversteer must be established and defined for control. The Phase I effort of the RCRV did not address operation from outside of the vehicle and constrained speed significantly, therefore measurement of speed, roll, and pitch were not deemed mandatory in the control algorithm.

The most significant variation of the software system from the existing ARTS controller was the introduction of a feedback loop nessesitated by the ackerman steering. The ARTS VCU does not react to any input with the exception of operator commands. Thus, the control loop within the VCU only executes at the rate that inputs from the joystick are received. In contrast, the steering mechanism on the P-19 requires constant control as the steering motor is engaged by applying a signed voltage to it. The applied voltage determines the speed of the motor's rotation and the torque of the rotation is based on current applied. If no feedback is present, the control algorithm would simply apply and maintain a set voltage representative of the joystick position. In other words, the motor would keep turning until a limit was reached. An absolute encoder

was integrated to provide feedback in the form of angular information on the steering angle. A control algorithm was developed that uses this information to characterize and control the vehicle steering digitally. The modified software implements a feedback loop that takes wheel position data from the encoder and compares it to a desired position on the joystick. The difference in these two positions is then used to implement a ramp function to compensated for convergence therefore insuring correct absolute vehicle heading. The new control algorithm allows the joystick to act as a steering device for the vehicle and provides a more natural control system.

4.0 TEST AND EVALUATION

At the completion of software development and hardware implementation, a test team conducted tests to assess the ability to control the P-19 via joystick. These tests were designed to satisfy the design requirements set forth in the project plan. These tests addressed many issues not anticipated in the design cycle of Phase I. A typical vehicle throttle system allows for a smooth linear increase in vehicle RPM's. However, on the P-19 the throttle system does not function in this manner. The throttle control algorithm was design to provide a smooth increase in throttle for values within the range of 128 to 255 that equate to voltages of 3.2 VDC to 2.4 VDC. The throttle actuator was observed to verify this. Test results show that the throttle actuator does move as directed, but the throttle system on the P-19 only responds to a command range between 158 and 185 (3.0125 VDC to 2.84375 VDC). A possible explanation of this is that the P-19 was never designed to have a throttle control such as a commercial truck; in fact the throttle is actuated via a pneumatic solenoid that is either ON or OFF. Therefore the valve that controls the fuel flow was also designed to be either fully open or closed. One solution to address this problem is to scale the command range to match the 28 values that really do provide for control. More realistically, a non-pneumatic throttle is required.

The steering rate tests provided a baseline data set in which future steering algorithms could benefit. These tests were conducted on a stationary vehicle, thus imphasizing the impact of the loads by eliminating The steering rate was nearly linear when tested at light and medium loads, which validates the assumption that the steering motor controller produces an output to the motor that is proportional to the input to the controller. Unfortunately, when the vehicle is at a maximum load, the steering rate becomes non-linear. These non-linearities can be attributed to the friction coefficient of the wheel and the surface it is in contact with. A very precise feedback loop is necessary to combat the error that non-linear systems introduce. It would take an enormous amount of resources to fully characterize the vehicle at maximum load because of the huge amount of variables present; therefore any problems encountered will be addressed when needed. With these three test and other data gathered throughout Phase I, the design engineers have a valuable source of data for future enhancements on the P-19 RCRV project.

Testing of the overall control system was performed by an operator inside the vehicle. General operation was deemed satisfactory at low speeds, but as speed was increased it was apparent that rollover would be easily achieved. To prevent rollover, all subsequent testing was done with limited speed settings. This safety precaution prevented the characterization of turn performance and constraints at varied speeds and with varied loads.

5.0 CONCLUSIONS

The completion of the RCRV Phase I effort as documented herein, shows the viability of remote control systems for high speed, large, vehicle systems and it is recommended to proceed with Phase II with modifications in the program plan. As discovered during test and evaluation, further sensor feedback is required to achieve a safe control system.

The recommended tasks to further the Research and Development in the area of large Ackerman vehicle control systems include full remote control system implementation via a Radio Frequency (RF) link. Additionally, work performed in the course of the Phase I effort recommends the investigation of digitizing video and implementing a single RF link for remote control. The applicability of these efforts to remote control vehicles and robotics in general constitute their continuation.

The recommended approach to Phase II is to proceed with the above tasks in the following manner:

- Implement full RF control of previous remoted functions via ARTS OCU to include shifting,
- Investigate throttle control for agent dispensing while driving,
- Implement redundancy in steering position encoders,
- Install variable throttle control and implement safety off for failure,
- Proceed with implementation of single RF Link (with Digital Video) to replace FreeWave/Trontek Radios (AOCU development).

In summary, known vehicle dynamics are critical to the successful implementation of tele-operated or semi-autonomous vehicle systems. Prior to operation of the hardware, simulation based on accurate models of the vehicle system should be performed. Safety parameters must be set early on addressing both control system fault tolerance and operator procedures.

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